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14. ABSTRACT
The UCLA National Center for Research on Evaluation, Standards, and Student Testing (CRESST) designed and developed a knowledge mapping authoring system intended to be simple and user-friendly, requiring a minimal number of clicks to navigate, but highly functional. The authoring system is intended to allow a diverse set of users to create, modify, adapt, and reuse knowledge mapping tasks. Various scoring options provide information on student performance on different dimensions and at different levels of stringency. The system stores student data and thus performance can be monitored over time. This report introduces knowledge mapping and provides guidelines on the creation of knowledge mapping tasks, and then describes the operation of the CRESST Human Performance Knowledge Mapping Tool Authoring System.

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CRESST Human Performance
Knowledge Mapping Tool Authoring System

Deliverable – March 2004

Knowledge, Models, and Tools to Improve the
Effectiveness of Naval Distance Learning

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Abstract

Effective delivery of advanced distributed learning (ADL) training to individuals in a Naval environment requires tools to support the creation and administration of assessment tasks. We have developed a knowledge mapping authoring system intended to be simple and user-friendly in its interface, but highly functional requiring a minimal number of clicks to navigate. The authoring system is intended to allow a diverse set of users to create, modify, adapt, and reuse knowledge mapping tasks. Various scoring options provide information on student performance on different dimensions and at different levels of stringency. The system stores student data and thus performance can be monitored over time. This report introduces knowledge mapping and provides guidelines on the creation of knowledge mapping tasks, and then describes the operation of the CRESST Human Performance Knowledge Mapping Tool Authoring System.

Introduction

The Navy-wide distributed learning training vision is to deliver quality training—to the right people, at the right time, and at the right place—as part of a career-long training continuum supporting Navy operational readiness and personal excellence. Achieving this vision of delivering learner-centric training to individuals will require maximizing the overlap between instruction—its format, pacing, and complexity—and the individual's cognitive, affective, and learning predispositions and preferences, deficiencies, and strengths. Attaining this capability will help equip Sailors and Marines with effective mission-essential competencies when and where needed at an affordable cost.

A critical first step in developing learner-centric systems is gathering quality information about an individual's competency in a skill or knowledge domain. Such information includes, for example, an estimate of what trainees know prior to training, how much they have learned from training, how well they may perform in a future target situation, or whether to recommend remediation content to bolster a trainees' knowledge.

One tool designed to assess a trainee's understanding of a content domain via graphical representation is the CRESST Human Performance Knowledge Mapping Tool (HPKMT), which requires trainees to express their understanding of a content area by creating knowledge maps. Previous reports have covered the development and functionality of the HPKMT (Chung, Michiuye et al., 2002, 2003). This report presents an overview of how to create knowledge mapping tasks in general, as well as a review of the CRESST-developed authoring system used to create tasks delivered by the HPKMT. In addition to creating tasks, the authoring system is used for user administration (e.g., creating users of the HPKMT and assigning knowledge mapping tasks to them) and for automated scoring of maps.

Introduction to Knowledge Maps

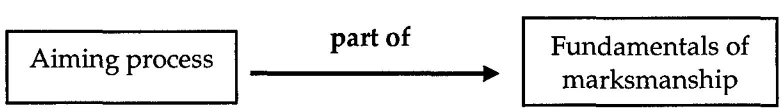
Research on expert knowledge structures suggests there exist qualitative differences between how experts and novices categorize and represent a domain. Experts tend to organize their knowledge in a principled manner, resulting in knowledge structures that are semantically and syntactically richer, more detailed, and more interconnected. A cohesive and integrated knowledge structure enables

better access not only to background knowledge but to more structured knowledge for learning and thinking about new concepts. By contrast, novices tend to rely on surface features which lead to more superficial relationships between concepts and to poorly connected knowledge structures. Research also suggests that as novices become more expert-like in conceptual understanding, so too do their corresponding knowledge structures (Chi, Feltovich, & Glaser, 1981; Gobbo & Chi, 1986).

One way for trainees to express their understanding—and hence one source of data for assessing their understanding—is for them to create knowledge maps of the domain of interest. Knowledge maps are network representations, where nodes represent concepts and labeled arcs describe how concepts are related. The basic unit of meaning is the concept-link-concept tuple, also called a proposition. There exist various knowledge map formats. For example, a declarative knowledge map is a representation of facts, principles, or concepts in a given area. A procedural knowledge map represents a process or procedure. In this case, the nodes would be steps in the process, and the arrows indicate the order of these steps. Procedural maps may involve solving problems, forming plans, or making decisions and arguments. A physical knowledge map represents spatial or geographical placement of concepts and/or relationships. For example students might be asked to put in place all the states which make up the United States to demonstrate understanding of geography.

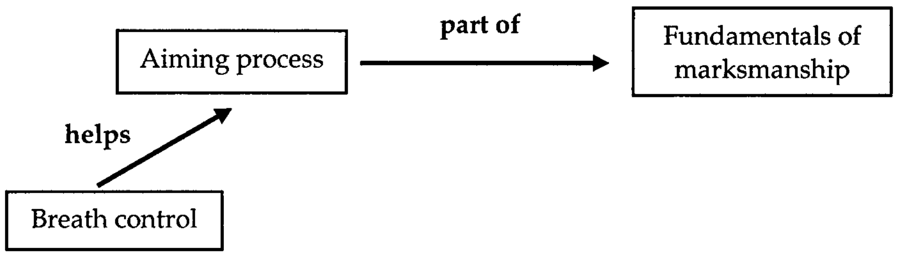
We have developed and tested the use of knowledge maps (primarily declarative) for assessment purposes in a variety of domains and populations (e.g., rifle marksmanship with Marines; risk management with U.S. Navy engineering duty officers; physiology concepts with elementary school students; environmental science with middle school students; genetics with college students; U.S. history with high school students; contaminant transport systems with advanced civil engineering students).

The following presents how a declarative knowledge map could be constructed in the domain of rifle marksmanship. In the domain of rifle marksmanship, for example, the statement, *Aiming process is a fundamental part of marksmanship*, can be simplified and represented in the following way:

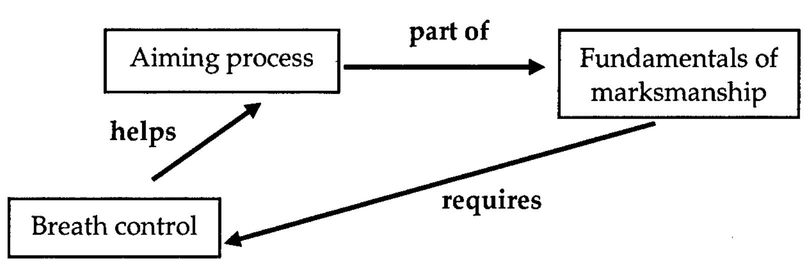


In the above proposition, *Aiming process* and *Fundamentals of Marksmanship* are two concepts related to each other through the link *part of.*

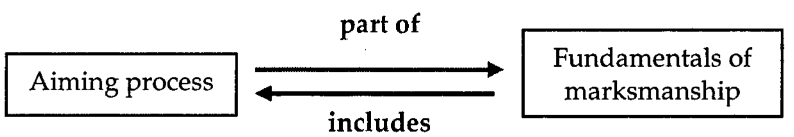
Each proposition is read as its own complete thought. In order to introduce a related idea another proposition must be created. For example, *Breath control* can be associated with *Aiming process* through the link *helps,*



and to *Fundamentals of Marksmanship* through the link *requires,*



Additionally, concepts can be related to one another in several ways, i.e., by changing the direction of the link. In general, it is recommended to choose one descriptor which best describes the relationship between two concepts.



There are two general perspectives on how knowledge maps can be organized. The first perspective reflects a hierarchical organization where the hierarchical structure is inherently meaningful. The second perspective reflects a network organization where meaning is based on the collection of relationships among concepts.

Hierarchical organization. As concepts and links accumulate in a knowledge map, the map begins to take on a structure that is both semantically richer (more meaningful links) and better integrated (more connections). As defined by Ausubel (1963), learning is the integration of new ideas, or concepts, into preexisting

knowledge structures. Concepts are represented in a hierarchical fashion with the most inclusive, most general concepts at the top of the map and the more specific, less general concepts arranged hierarchically below. This approach is especially useful for well-structured disciplines such as the sciences.

Evaluation of knowledge maps from this perspective was specified by Novak and Gowin (1984). Novak and Gowin's rubric is one of the earliest and most commonly used methods of scoring knowledge maps. Their method considers hierarchy as an important component of the scoring, as well as propositions, cross-links, and examples. In terms of hierarchy, credit is given for each hierarchical level showing subordinate concepts at a lower level as more specific than their parent concepts. Each valid and meaningful proposition is also credited, as are examples and cross-links. Cross-links are links between different hierarchical levels. Novak and Gowin's scoring scheme is weighted heavily toward the hierarchical structure of the map. The theoretical rationale for Novak and Gowin's scoring scheme is based on Ausubel's theory of learning, particularly the idea of subsumption (new ideas can be subsumed under more general concepts) and progressive differentiation (as learning occurs, there is more differentiation among the concepts, which is shown by the inclusion of more propositions and cross-links).

Evidence from several studies suggests that Novak and Gowin's (1984) scoring scheme can differentiate between high- and low-knowledge students in biology (Markham, Mintzes, & Jones, 1994) and between first-year and advanced pediatric residents studying seizures (West, Pomeroy, Park, Gerstenberger, & Sandoval, 2000). This scoring scheme also appears to be sensitive to learning, as student map scores increased over instruction (Pearsall, Skipper, & Mintzes, 1997; West et al., 2000).

Network organization. The second perspective on how to organize knowledge maps is based on associationist memory theory (Deese, 1962, 1965), wherein meaning is represented as associations among concepts. Under this model, structures are not limited to a hierarchical framework, but instead allow for a variety of relationships among concepts.

Evaluation of knowledge maps from this perspective is typically performed in one of two ways: (a) scoring each proposition on its quality using a rubric, or (b) comparing each student map against a criterion map, proposition by proposition.

Proposition quality scoring typically considers only the propositions contained in the map and not its configural properties. Each proposition is evaluated in terms

of its quality. For example, Osmundson and colleagues used a proposition quality score as one measure of the quality of students' knowledge maps (Osmundson, Chung, Herl, & Klein, 1999). Each proposition in a student's map was scored on a 4-point scale, ranging from 0 (invalid/illogical) to 3 (reflects scientific understanding).

Proposition quality scoring methods have been found to differentiate high-knowledge students from low-knowledge students (e.g., Ruiz-Primo, Schultz, Li, & Shavelson, 1997a, 1997b). Scores have been shown to correlate moderately with other measures of content knowledge in other formats (e.g., essays, multiple choice tests), classroom end-of-unit tests and standardized tests of reading, math, and science (Rice, Ryan, & Samson, 1998), and physics problem solving (Austin & Shore, 1995).

The second scoring method for network-based knowledge maps is to compare a student's map against a criterion map. The basic measure is the number of propositions in the student map that are also in the referent map. Example referents include a domain expert's map, a composite map of experts, or the instructor's map.

The utility of a referent-based scoring approach is that it is efficient and it has been validated under a variety of conditions. For example, Ruiz-Primo, Schultz, Li, and Shavelson (2001), in addition to using proposition accuracy scores, also scored students' maps against an expert's map. The correlation between the proposition accuracy score and expert-based score was sufficiently high for Ruiz-Primo et al. to conclude that an expert-based method was the most efficient scoring method (i.e., in terms of scoring time and reliability of scores). Similar results were found by Osmundson et al. (1999) and Chung, Harmon, and Baker (2001).

In general, scoring student knowledge maps using expert-based referents has been found to discriminate between experts and novices (Herl, 1995; Herl, Baker, & Niemi, 1996), discriminate between different levels of student performance (Herl, 1995; Herl et al., 1996), relate moderately to external measures (Aguirre-Muñoz, 2000; Herl, 1995; Herl et al., 1996; Klein, Chung, Osmundson, Herl, & O'Neil, 2002; Lee, 2000; Osmundson et al., 1999), detect changes in learning (Chung et al., 2001; Osmundson et al., 1999; Schacter, Herl, Chung, Dennis, & O'Neil, 1999), and be sensitive to language proficiency (Aguirre-Muñoz, 2000; Lee, 2000).

Guidelines for Creating Knowledge Maps

The creation of knowledge mapping tasks has 7 steps (see Table 1 for summary):

1. **Select domain area and specify learning objective.** Since concept map structures are dependent on the context in which they will be used, it is best to identify the learning objective, or the particular problem or situation one is trying to understand, e.g., the fundamental elements of rifle marksmanship, the mechanics of inheritance, how photosynthesis works, features of different physiological systems and how they interact, or the factors behind the 1930s Depression.

2. **Identify key ideas.** With the learning objective in mind, experts review curriculum material and generate lists of the most important main ideas. Experts can be the course instructor or a designated content specialist. A rank order of the list is established from the most general, most inclusive concept to the most specific, least general concept.

3. **Construct preliminary map.** Using the list of concepts, experts construct a preliminary concept map, linking concepts with links. Note that concepts are usually nouns, and links, verbs. See the next section for guidelines on selecting links.

4. **Review maps.** Check the map to ensure all concepts are depicted and that the relationships between concepts are meaningful and complete. Check also for overall organization of the maps for density (number of links), level of complexity, and interconnectedness (that concepts are interrelated, i.e., no concept is isolated).

5. **Modify maps according to student level.** Adjust the maps according to student level. Will students be able to understand the meaning of the concepts and links or do the terms have to be simplified for student comprehension?

6. **Final list of concepts and links.**

7. **Final knowledge map.** Experts create final map based on revised list of concepts and links. This process should be much quicker than creating the preliminary map.

Table 1

Summary for Developing a Knowledge Mapping Task

Step	Procedure
1	Select domain.
2	Experts identify key concepts within that domain, i.e., major ideas and more specific, associated ones.
3	Experts create preliminary map with links.
4	Expert maps compared and reviewed.
5	Concepts and links are modified according to student level.
6	Create final list of terms and links.
7	Experts create final knowledge maps.

Guidelines for Selecting Links

According to Jonassen (1996) the most difficult part of semantic networks is the linking process. Good links, which are usually verbs, describe not only precisely but completely the nature of relationships between all the ideas. And because ideas can be related to one another in several ways, and on different levels, it might often be necessary to either select the more meaningful link or have more than one link in different directions between concepts.

The following is a list of guidelines for link selection (Jonassen, 1996).

1. **Preciseness and succinctness.** Try to avoid surface links, such as *is connected to*, *is related to*, or *involves*, for they do not tell anything meaningful about the relationship. Select instead links that discriminate meaningful differences on functional, temporal, or causal levels. For a list of relational categories, see Table 2.
2. **Parsimony.** Try not to use more links than are necessary. For example, if 5 different links will describe all the relationships among the terms, do not use more than 5. Also, do not use different links that mean the same thing, e.g., *attribute of*, *property of*, and *characteristic of.*
3. **Consistency.** The meaning of any link should be the same each time it is used.

4. **Avoid over-reliance on one or two links.** A predominance of a few links reflects a narrowness of thinking. Additionally, it implies the links are too general and that other, more specific links might better describe the relationship between concepts. One strategy is to calculate the proportions of relational categories among the links, i.e., frequency of causal, characteristic, functional, etc., to ensure a balanced representation.

5. **Calculate *term:link* ratio.** There should be fewer links than terms. This goes back to the idea of parsimony.

Although the HPKMT provides no direct measures of the quality of propositions in the knowledge maps, prior CRESST research has examined the semantic quality of links used. This approach, based on existing work on semantic and language structure (Evens, Litowitz, Markowitz, Smith, & Werner, 1980; Sowa, 1984; Wilkins, 1976), has identified nine common relational categories for knowledge map links (see Table 2, Chung, Baker, & Cheak, 2002).

Table 2

Relationship Categories For Knowledge Maps

Relationship category	Definition[a]	Example
Causal	*X* creates a change or effect on *Y*	*causes, leads to, increases, improves*
Characteristic	*X* is an inherent feature or characteristic of *Y*	*has, is*
Classification	*X* is a class, category or type of *Y*, or vice versa	*type of, example of*
Comparison	*X* involves a comparison in order to show a similarity, difference, or equality with *Y*	*similar to, different from, equal*
Conditional	*X* contingent on *Y*; a possible event	*may lead to, requires, necessary for*
Function	*X* designed for or capable of a particular function with regard to *Y*	*controls, transports, carries, use*
Location	*X*'s spatial relation to *Y*	*under, over*
Part-whole	*X* is contained within, or a part of *Y*	*part of, belongs to, made of, includes*
Temporal	*X*'s time relation to *Y*	*beside, during, follows, prior to*

[a]General form: *X* type-of-relationship *Y*, where type-of-relationship is the relationship category.

In considering the relationship between concepts, first determine the nature of the relationship [e.g., what kind of thing is it? (membership); What is it made of? (whole/part); What are its distinguishing features? (characteristic); What does it do? (functional)] and then select the appropriate descriptor, e.g., *is, made of, has, controls*, respectively. For an extended list of possible links, see Table 3.

Table 3

Sample Links (Adapted from Jonassen, 1996)

Relationship category	Examples	
Symmetric	has sibling	is same as
	has synonym	is independent of
	is opposite of	is equal to
	is near to	is opposed to
	is similar to	
Asymmetric		
1. Inclusion	composed of/is part in	contains/is contained in
(typically the most common)	has part/is part of	has instance/is an instance of
	has example/is example of	includes/is included in
2. Characteristic	has characteristic/is characteristic of	has attribute/is attribute of
(second most common)		has type/is type of
	has property/is property of	defines/is defined by
	has kind/is kind of	models/is modeled by
	describes/is described by	implies/is implied by
	denotes/is denoted by	has disadvantage/is disadvantaged
	has advantage/is advantage of	has size/is size of
	has function/is function of	is higher than/is lower than
	is above/is below	
3. Action	causes/is caused by	used/is used by
	solves/is solution for	exploits/is exploited by
	decreases/is decreased by	increases/is increased by
	destroys/is destroyed by	impedes/is impeded by
	influences/is influenced by	determines/is determined
	enables/is enabled by	absorbs/is absorbed by
	acts on/is acted on by	consumes/is consumed by
	converted from/converted to	designs/is designed by
	employs/is employed by	evolves into/is evolved from
	generates/is generated by	modifies/is modified by
	originates from/is origin of	provides/is provided by
	requires/is required by	regulates/is regulated by
	sends to/receives from	
4. Process	has object/is object of	has output/output of
	has result/results from	has subprocess/is subprocess of
	has process/is process in	organizes/is organized by
	has input/is input to	proposes/is proposed by
	depends on/has dependent	concludes/is concluded by
5. Temporal	has step/is step in	has stage/is stage in
	precedes/follows	

HPKMT Authoring System Overview

The Web-based HPKMT Authoring System supports the online creation and maintenance of knowledge mapping tasks. The design of the system was based on the work of Chung, Baker et al. (2002). The near-term goal of the authoring functionality was to support research activities. A long-term goal was to develop an interface that is suitable for use by a wide audience (e.g., trainers, trainees, researchers, course managers).

The functionality of the Authoring System is outlined in the home page, which displays a site map (see Figure 1). New users unfamiliar with the system are advised to click on **Tasks** to begin creating a knowledge mapping task. From the **Tasks** page, a user can add all of the elements to make a complete knowledge mapping task.

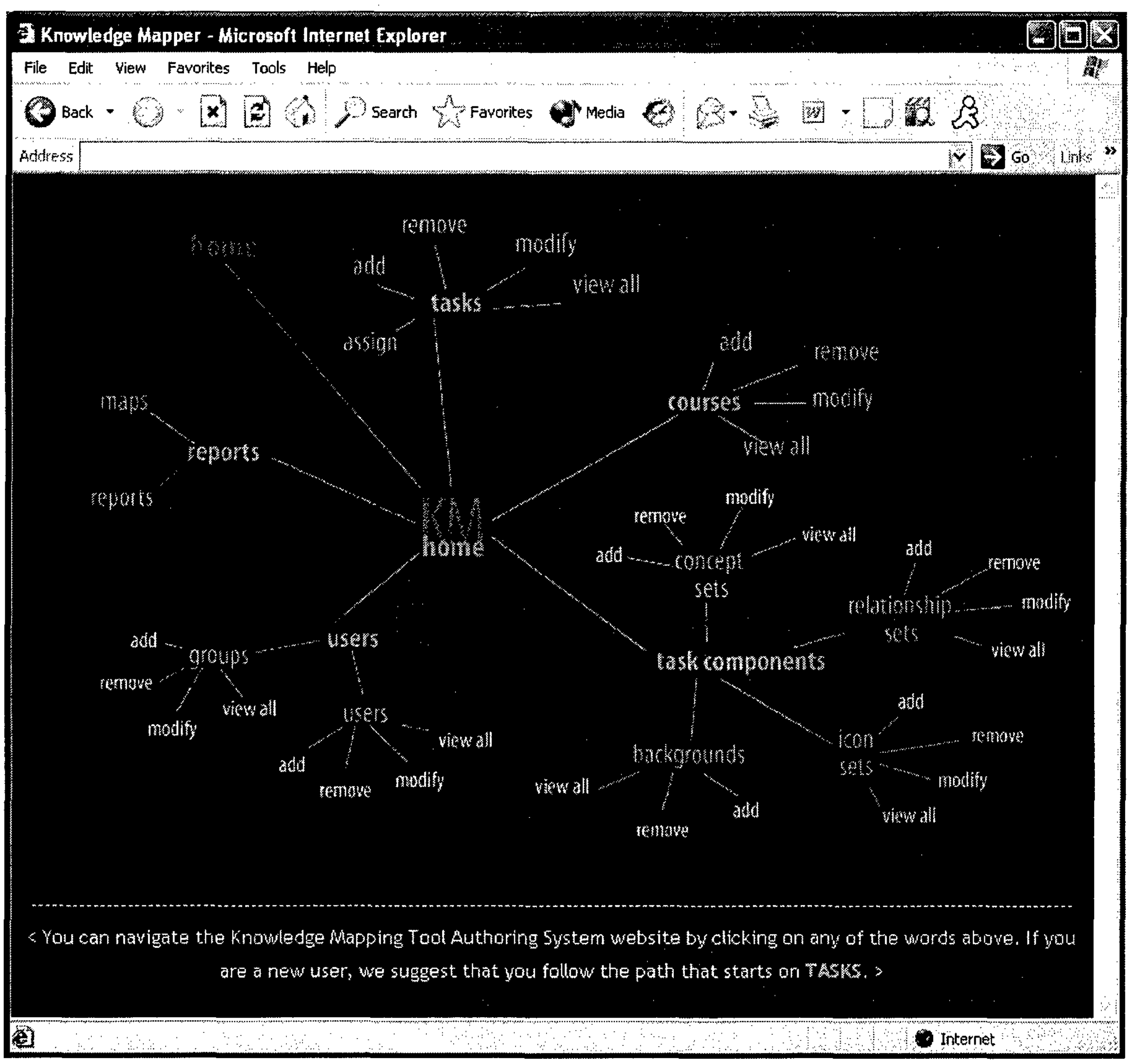


Figure 1. Home page of HPKMT Authoring System.

Users can click on any of the words in the graphic to perform a specific action, such as modifying a concept set or removing an icon set. Each of the boldfaced words is a major category (**Tasks**, **Courses**, **Task Components**, **Users**, and **Reports**); access to these is provided at the top of every page in the Authoring System.

To organize the set of tasks, users first create a course. A course consists of one or more knowledge mapping tasks. Each mapping task has properties associated with it, such as the set of concepts and links, the set of icons used, and the background of the canvas. Tasks can be created by using existing concepts and links or by creating new ones or augmenting existing sets. Users enter information about trainees and create login IDs for them to access the HPKMT software. Once trainees are entered in the system, they are assigned tasks. Individual trainees can be put into groups to make administration functions (such as scoring and assigning tasks) easier. In the following sections, each major functional area is discussed with accompanying screen shots.

Tasks

To create a new task, users go to **Tasks > Add**. In this page (see Figure 2), users provide a task name and select the course to which this task belongs. For Task Type, users set the kind of knowledge representation of the task; users can select from declarative, procedural, and physical. Task Mode is used to designate whether the student can only select concepts and relationships, only type in concepts and relationships, or do both.

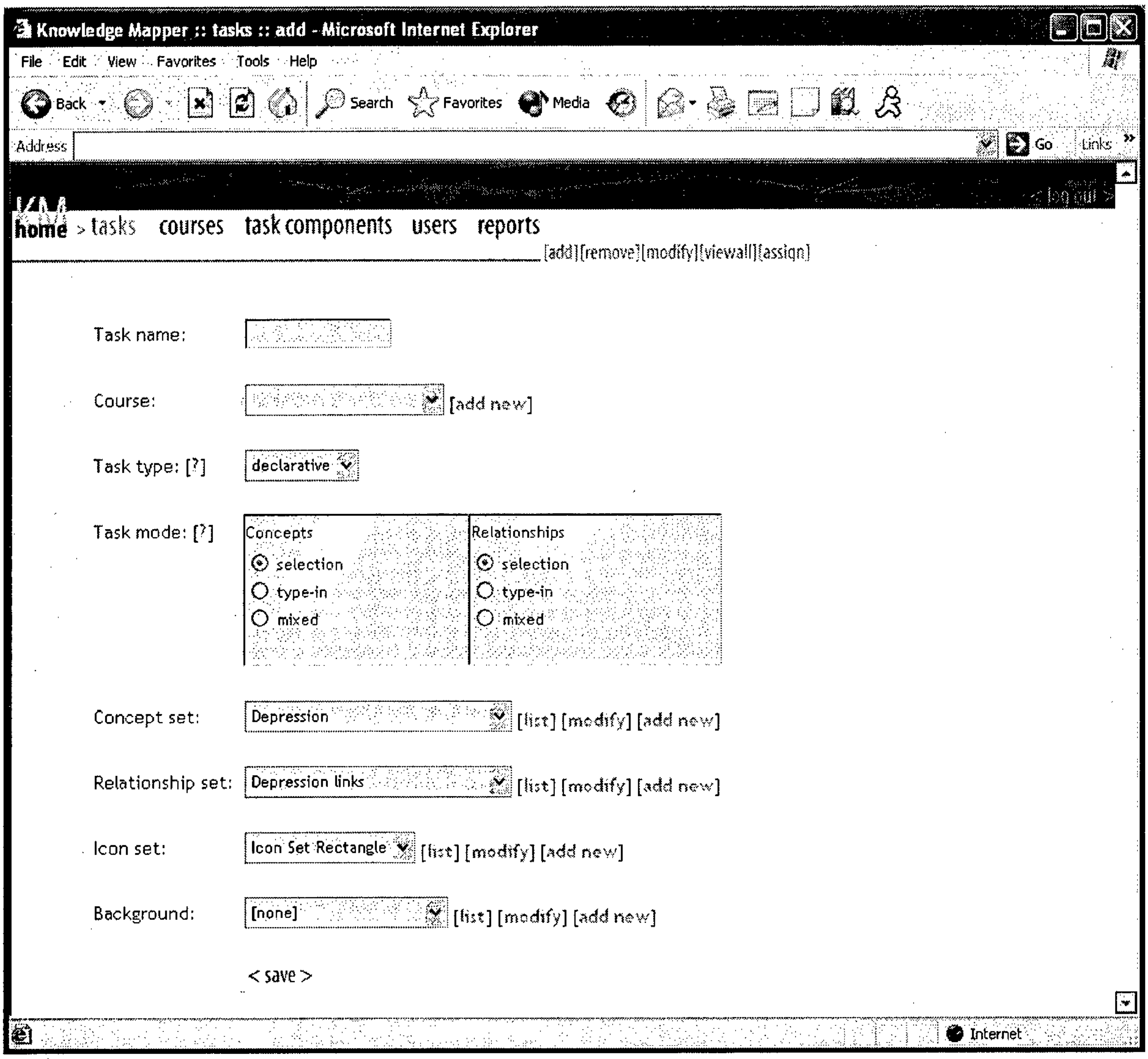


Figure 2. Add Task page.

Users can either select existing concept, relationship, and icon sets and backgrounds to use in their task, modify the existing entities, or create their own. Users can view the contents of existing entities by clicking on **List** (see Figure 3). When users are done setting the specifications of their task, they click on **Save** and are taken to the **Assign** page.

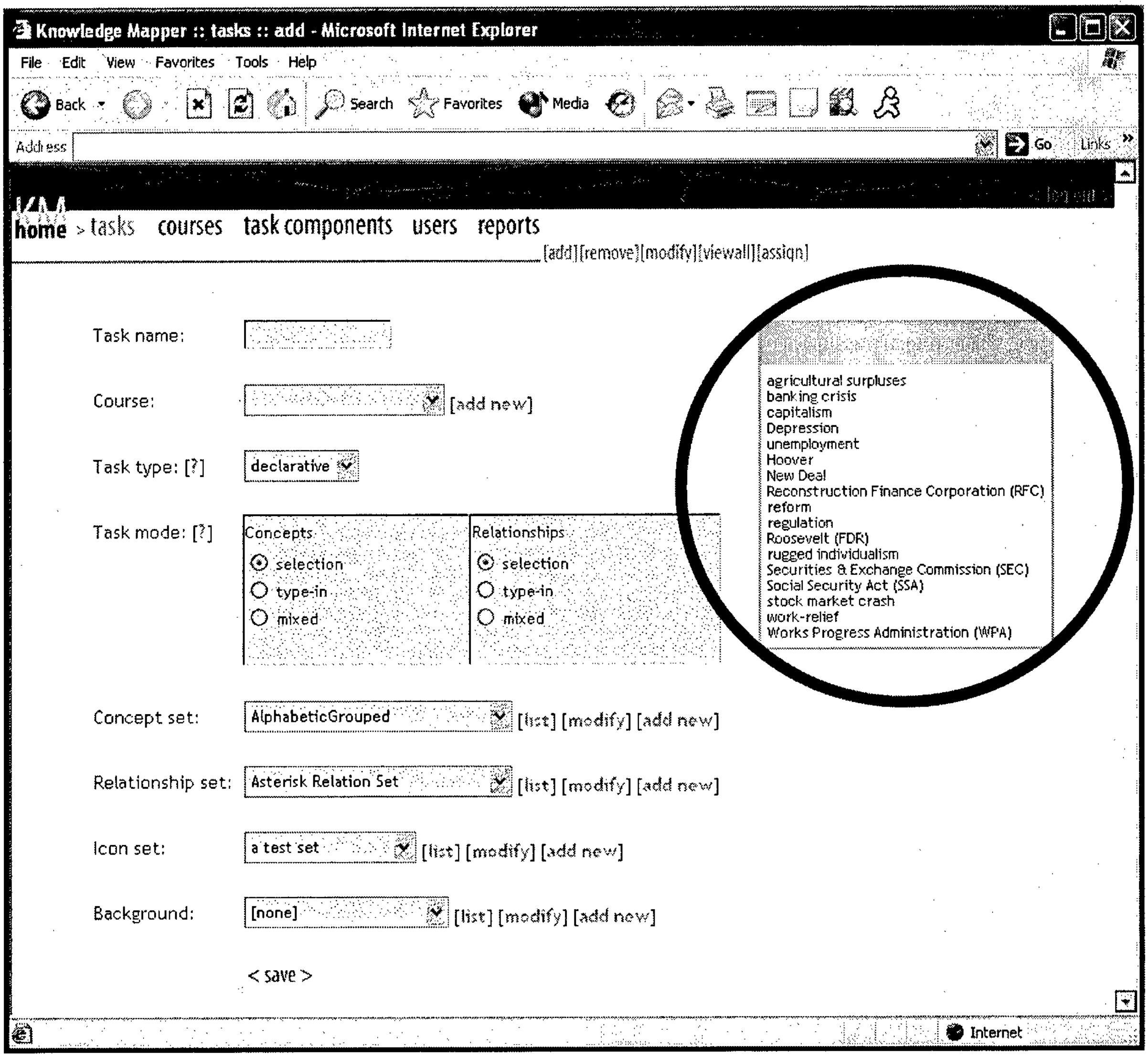


Figure 3. List Concept set view.

Courses

By bundling multiple tasks into a course, users can organize tasks in the Authoring System. A task is assigned to a course from the **Tasks** page; a course can be created from that page or through the **Courses** link. In addition, courses can be modified, deleted, or viewed through the Courses main page.

Task Components

Tasks are necessarily made up of three components: a concept set, a relationship set, and an icon set. In addition, a background can be selected, usually for tasks where placement of nodes is as important or more important than the

relationships between them. If no background is selected, the drawing canvas is white.

Users who want to manipulate individual task elements instead of the entire task can go to **Task Components** and select the element (**Concept Sets**, **Relationship Sets**, **Icon Sets**, or **Backgrounds**) they wish to work on.

Task components are independent of tasks, so they can be reused across tasks. Users should be aware however that changing a task component that is already in use in a task could have adverse effects.

Concept Sets

To create a new concept set, users click on **Task Components > Concept Sets > Add**. Users will see a form as presented in Figure 4. Users name the task and also provide a description, which can be particularly useful if there are multiple versions of a concept set for one subject area or task (e.g., the user can note the date modified, version number, or notes about edited concepts).

Users then type or paste the concepts into the text box—concepts are separated by carriage returns.

If users want the Authoring System to alphabetize the concepts that were entered, they can check the box for "Alphabetical Order?" Otherwise, concepts will be presented in the HPKMT in the order they were entered by the user.

Users can also specify if they wish to have concepts grouped within the concept list. This means in the HPKMT when the concept list is displayed, concepts can be set apart from others by a thin gray line. Users may wish to use this function for tasks dealing with different categories of entities—for example, a concept list might separate people, places, and events, or for a physiology task, concepts related to the digestive system might be set apart from ones related to the circulatory system. To turn on concept grouping, users need to check the box next to "Group Category?" and also set apart the concept groups by entering separators in the concept list—two or more consecutive hyphens on their own line constitute a separator.

After concepts have been entered and preferences for the concept set have been checked, the user can click **Add** to save the concept set.

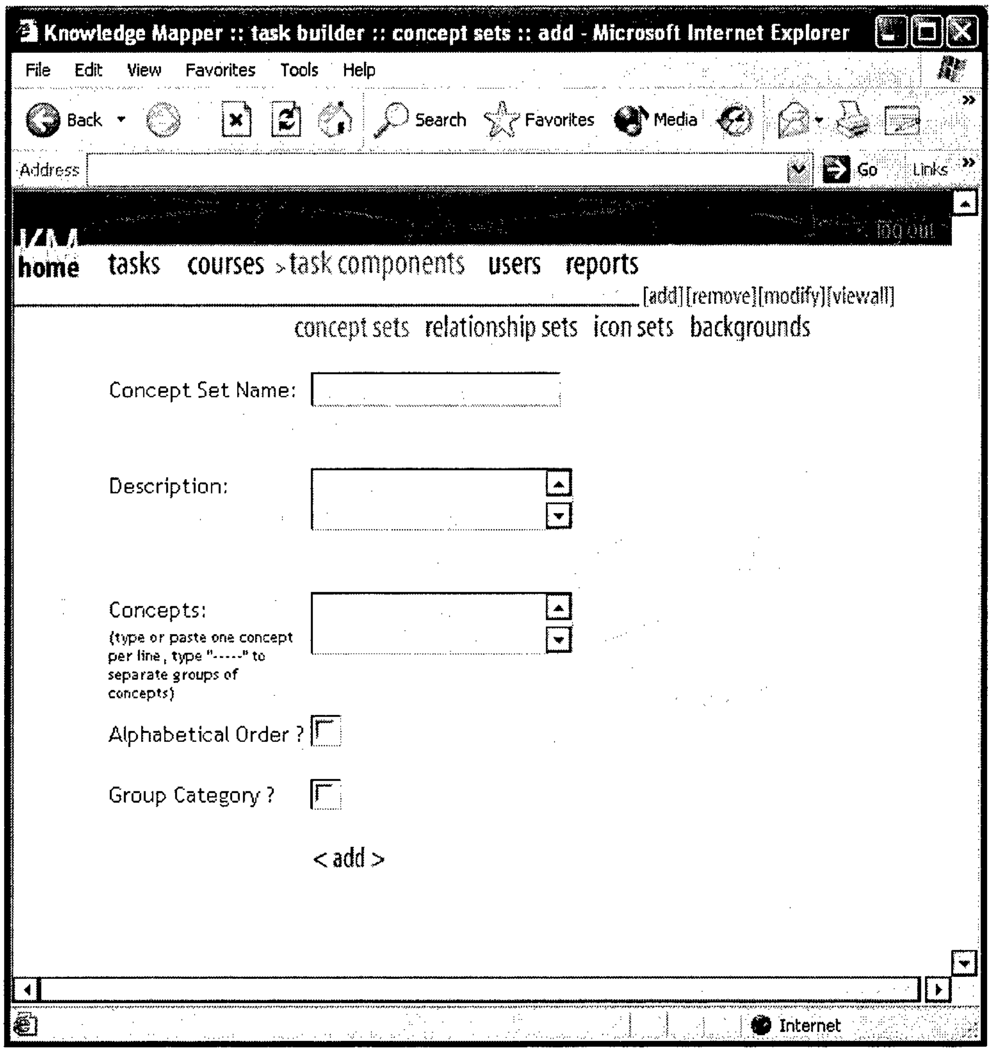


Figure 4. Add Concept Set page.

Users can click on **Concept Sets > View All** to review existing concept sets. From that page, they can also remove and modify concept sets, or they can also click on the Remove or Modify links near the top right-hand corner of the page. (The options to add, remove, modify, and view all are available for all of the functions in the Authoring System except for Reports.)

Relationship Sets

Relationship sets function similarly to concept sets. In the **Task Components > Relationship Sets > Add** page, users enter a relationship set name, description, and the set of relationships.

In addition, if users want to create a task that does not require students to label all links between concepts, users can check the box next to "Allow Label-less links?"

If this box is checked, in the HPKMT, the student will see the list of relationships (if any have been entered) and an additional option that says "[no label]." If the student selects "[no label]" for a relationship in the map, there will only be an arrow connecting the two concepts and no accompanying link label.

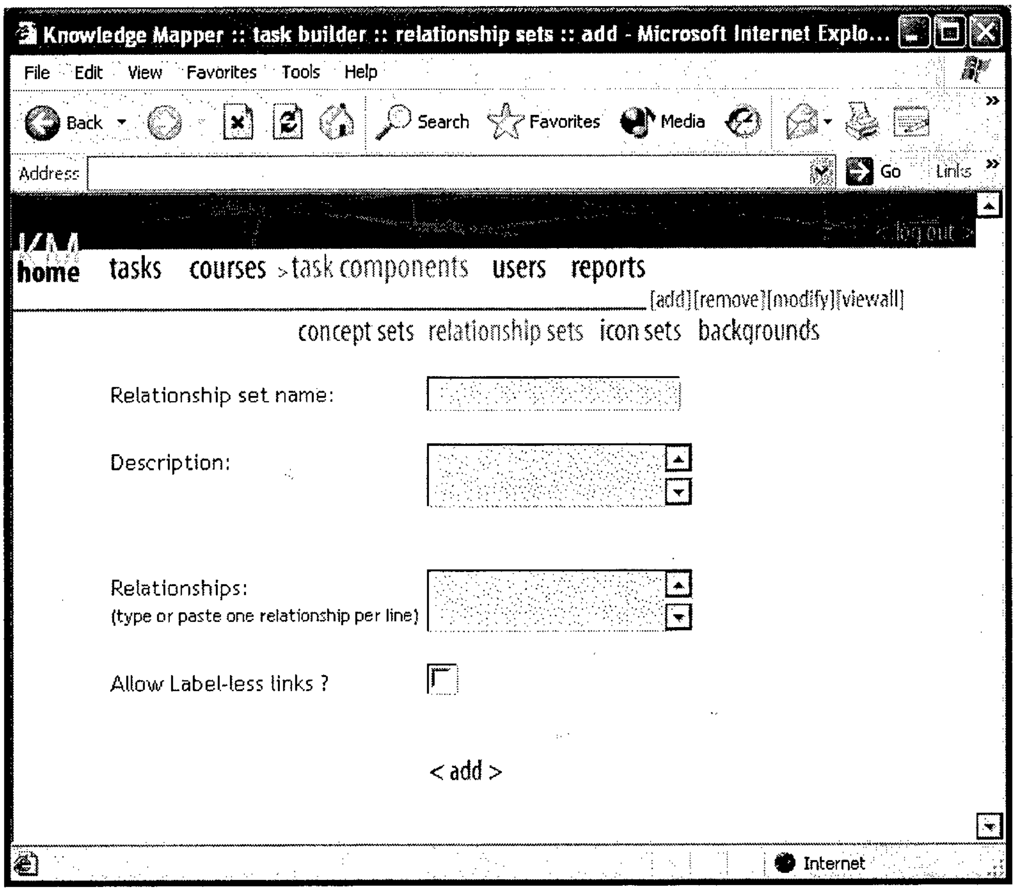


Figure 5. Add Relationship Set page.

Icon Sets

Icon sets are used to specify the concept symbols served up in the HPKMT. The most commonly used icon set represents a concept as a blue rectangle with the concept label within the box. If preferred, however, users can upload their own icons and create icon sets tailored to their tasks.

The specifications for icon files are on the **Task Components > Icon Sets > Add** page (see Figure 6). Users upload icons from their personal computers to the library by clicking on the **Browse** button and locating the picture file. After users click on **Add**, the picture file is uploaded to the library and appears in the window with the scroll bar at the bottom of the page.

One or more icons are then checked off to be added to the new icon set; after the user clicks **Add** at the bottom of the page, the icon set is available to be used in a task.

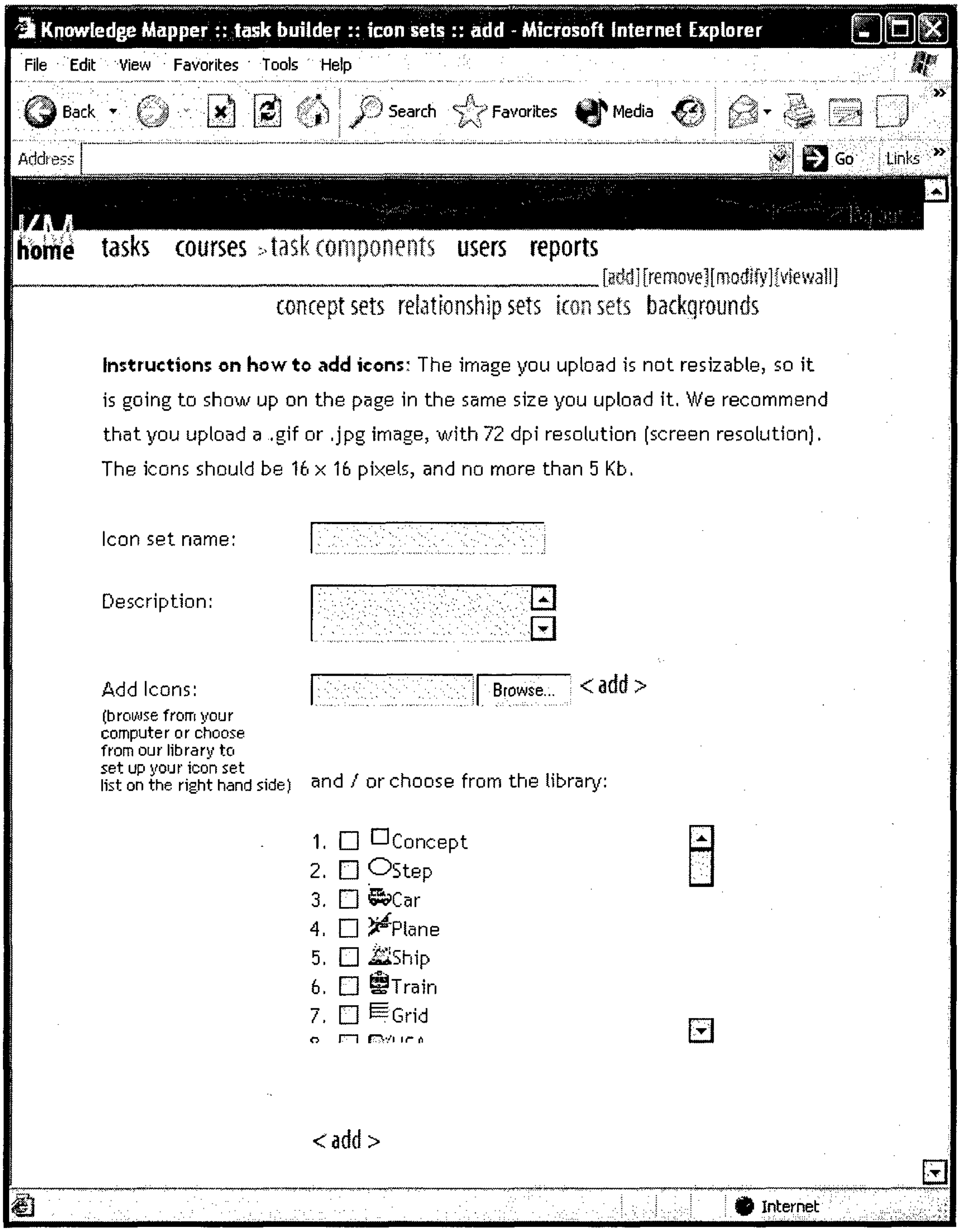


Figure 6. Add Icon Set page.

Backgrounds

The default for the canvas background in the HPKMT is a white mapping space, but some tasks may require users to place concepts or nodes on a background. Users can upload picture files to be used for canvas backgrounds in **Task Components > Backgrounds> Add** (see Figure 7).

Specifications on how to upload backgrounds are provided at the top of the page. The procedures for uploading backgrounds to the library and saving them are identical to those for icon sets.

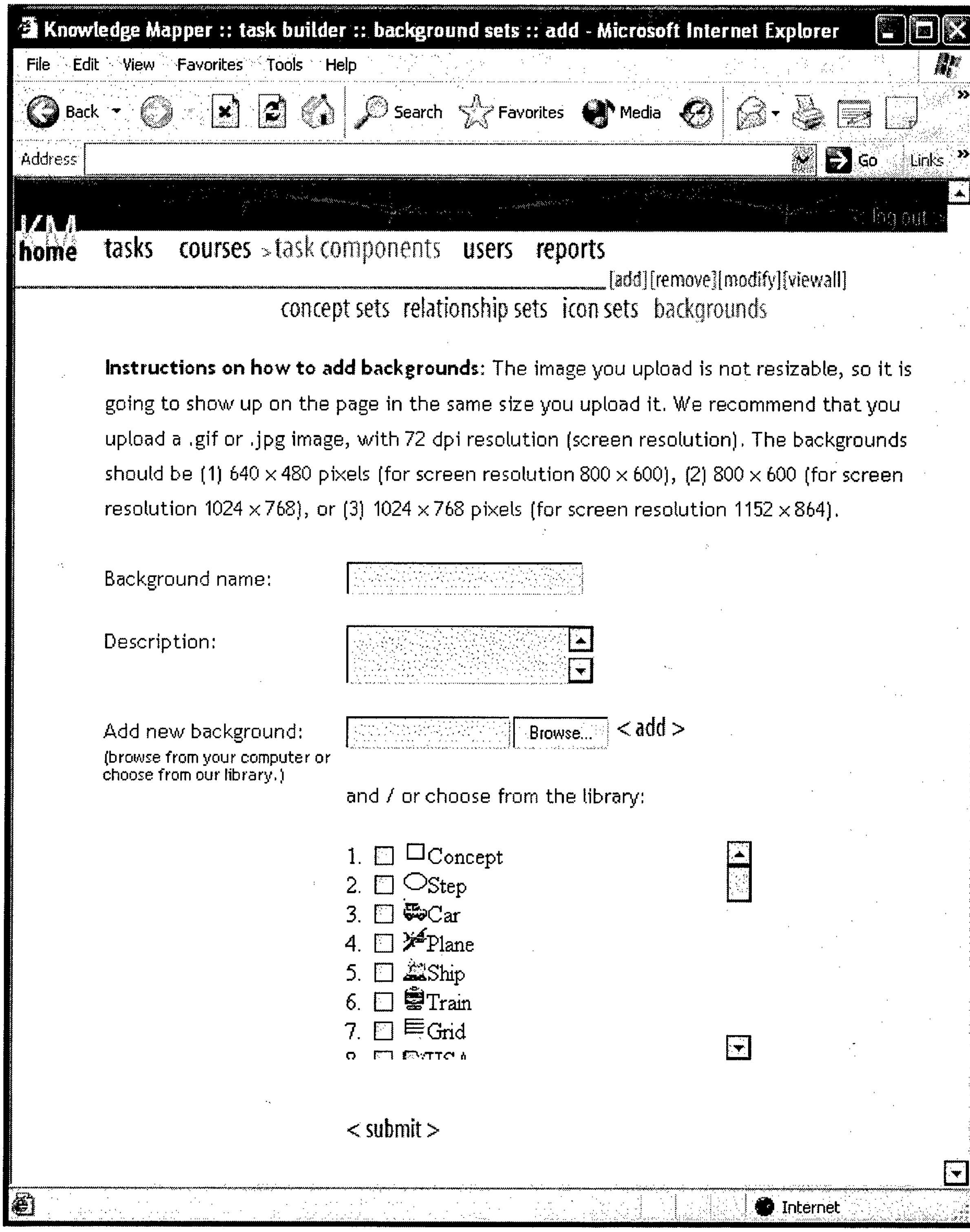


Figure 7. Add Backgrounds page.

Users

In order to use the HPKMT and create knowledge maps, a person needs to be set up as a user with a login and password. The form to add users (see Figure 8) allows for the easy entry of multiple users; information can be copied from a text file and pasted into the form. Commas separate the required elements of the user's profile (first name, last name, user name, and password). The user name is a unique login to access the HPKMT—e-mail addresses can be used to avoid potential conflicts with existing logins. Each user's information is separated by a carriage return.

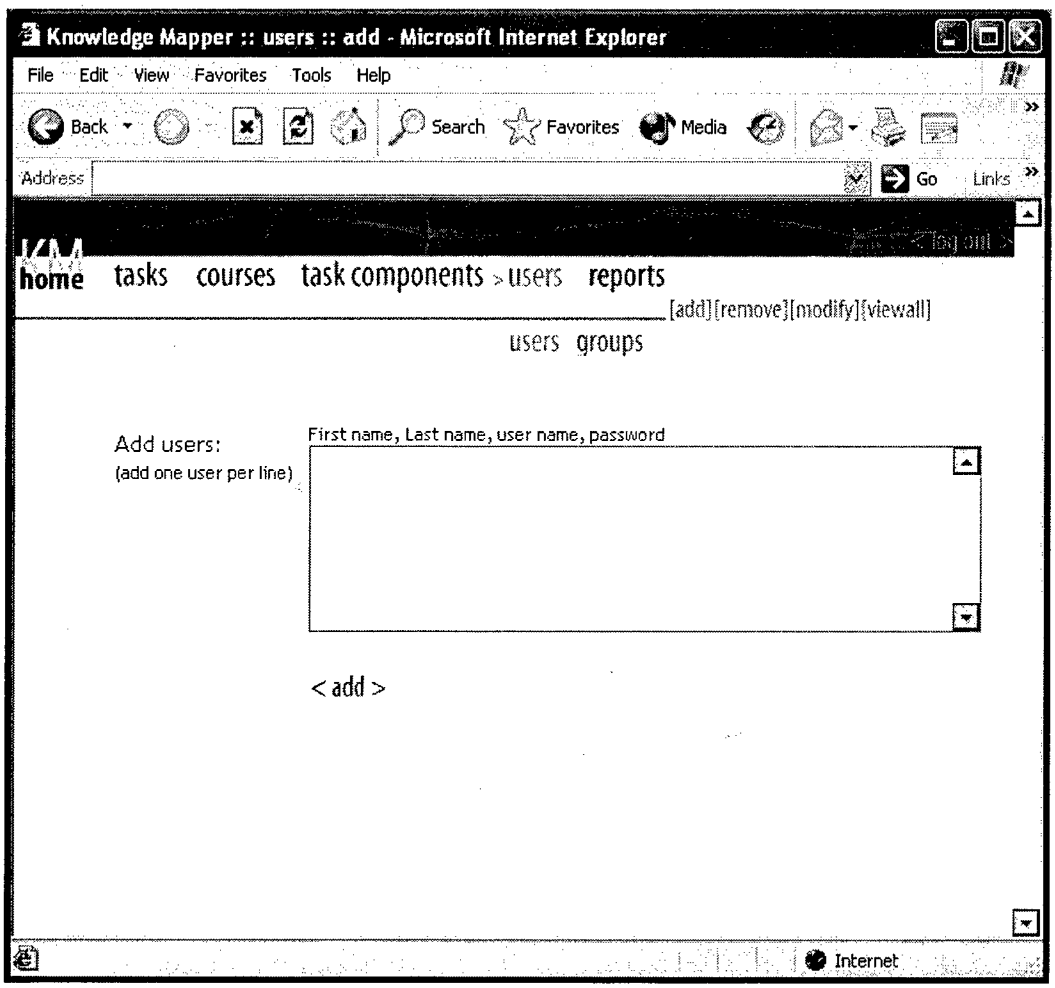


Figure 8. Add Users page.

In **Users > Modify** (see Figure 9), a fuller user profile is provided. If a user is to be designated an expert (someone who will create a criterion map for a task), User Type needs to be changed from Student to Expert. In this page, user information can be edited to correct misspellings or to change passwords as well.

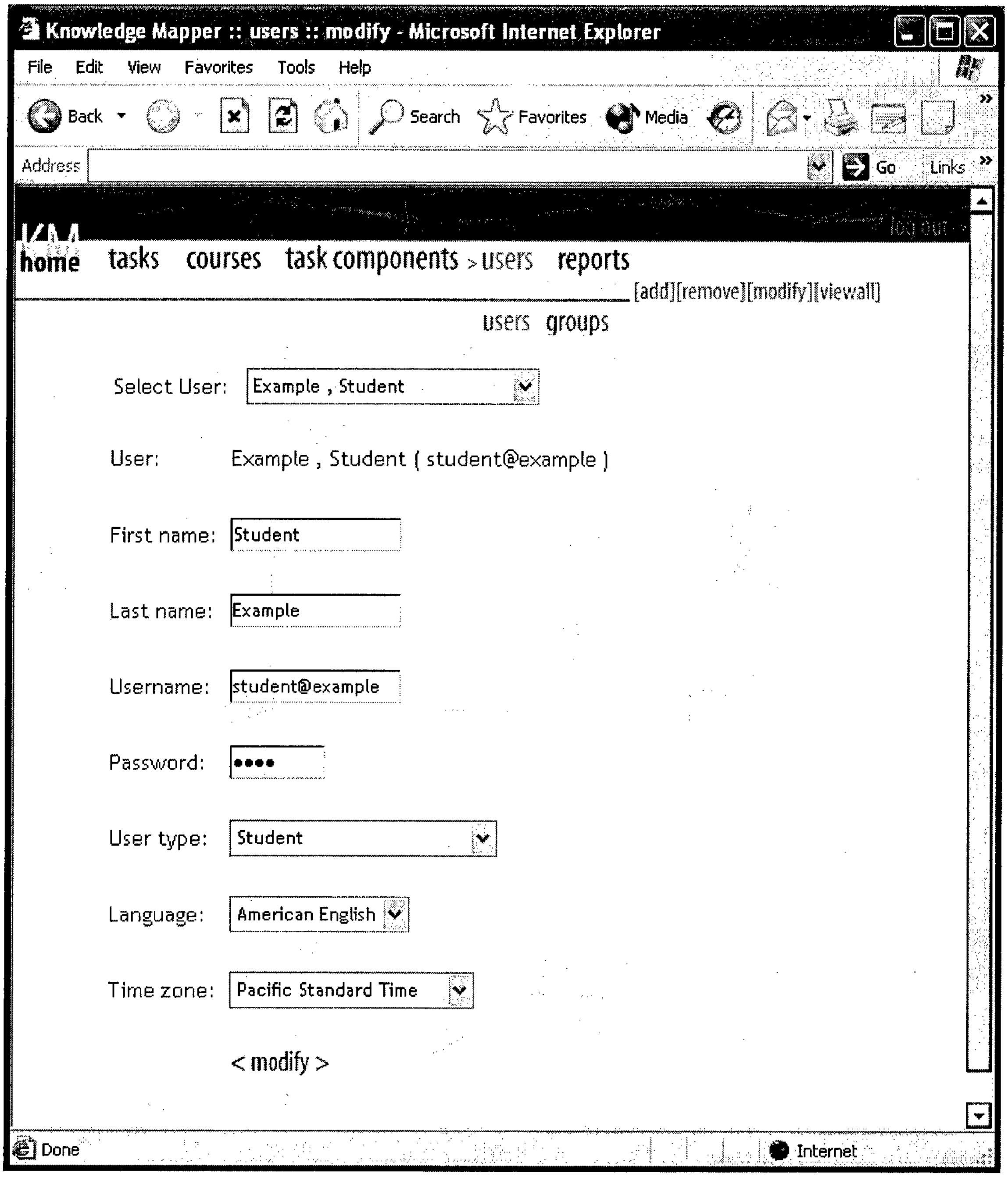


Figure 9. Modify User page.

Groups

Groups can be created to facilitate user management. Individual users must be selected when assigning tasks or generating score reports; grouping users can make these functions less cumbersome by eliminating the need to click on multiple users or to perform the same task repeatedly.

Reports

Several different scoring schemes have been developed, and continue to be developed, for knowledge maps. The HPKMT Authoring System is flexible enough to allow for the addition of new schemes as they are conceived. Currently there are three scoring schemes (two for declarative and procedural maps, one tailored for a specific physical mapping task) available in the Reports section (see Figure 10), but new ones can be integrated seamlessly.

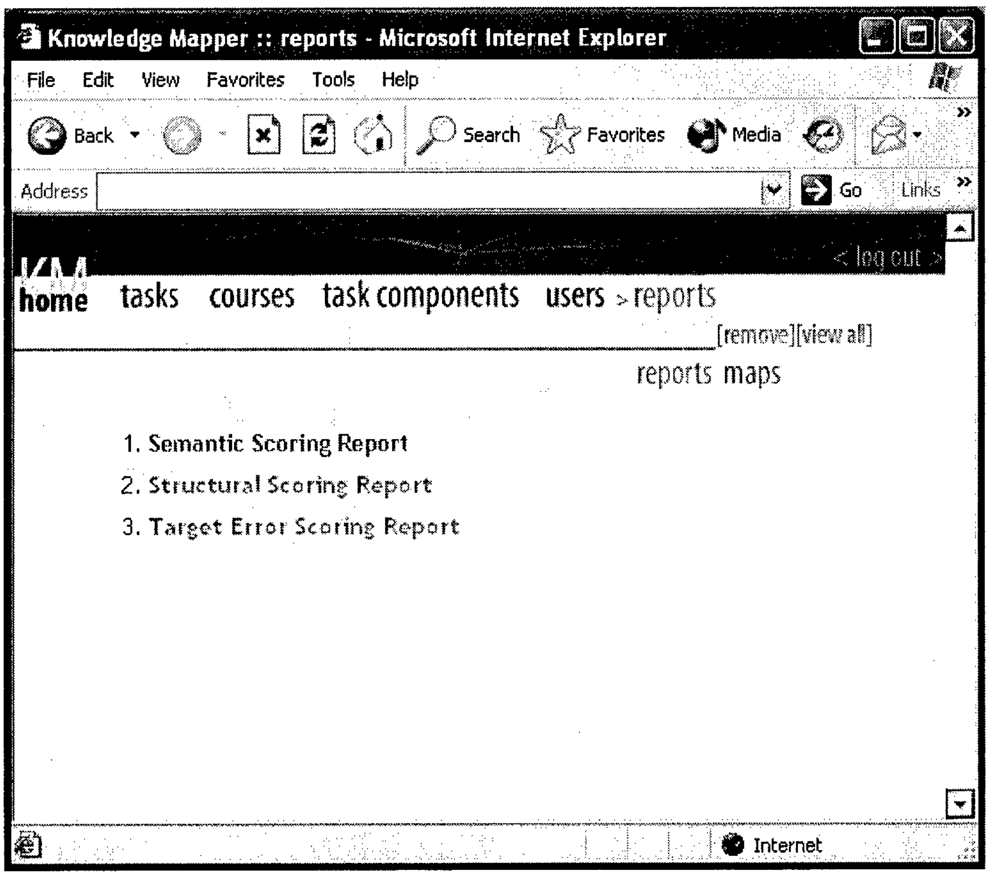


Figure 10. Reports page.

Semantic Scoring

Semantic scoring compares the propositions in a student's map to those in an expert's map. In the Authoring System, users select from a pull-down menu both the task and the expert who created the criterion map (see Figure 11). Then, a score report can be generated for all users who created a map for that task by checking the box next to "All Users," or if a score report is needed for only a subset of students, individual users or groups of users can be selected by using control-click.

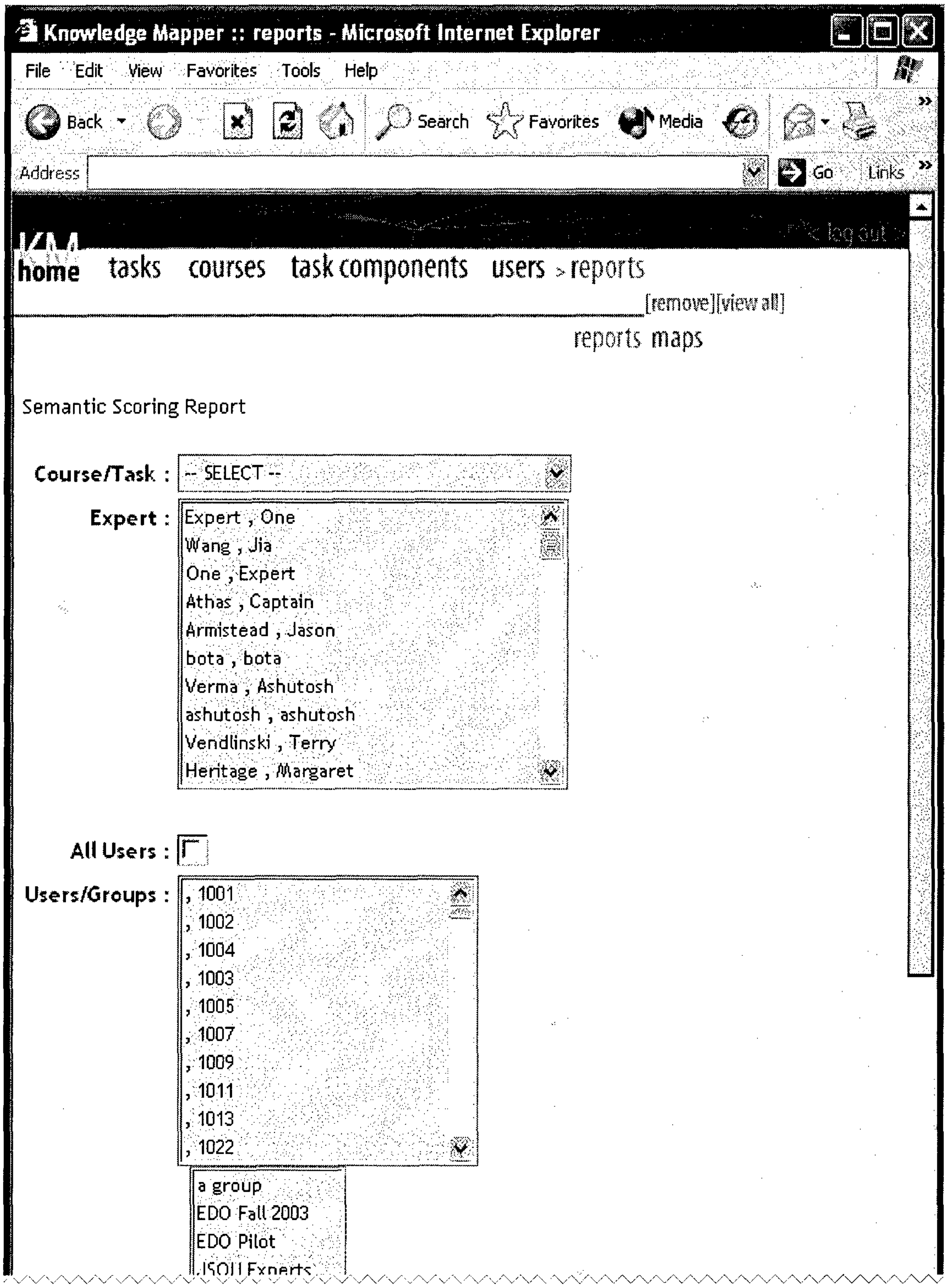


Figure 11. Semantic scoring specification page.

At the bottom of the semantic scoring report specification page are five checkboxes (see Figure 12). These are used to set the types of scores to be retrieved.

Descriptions of each type (Exact, Directionless, Linkless, Linkless with Direction, and Synonyms) are below.

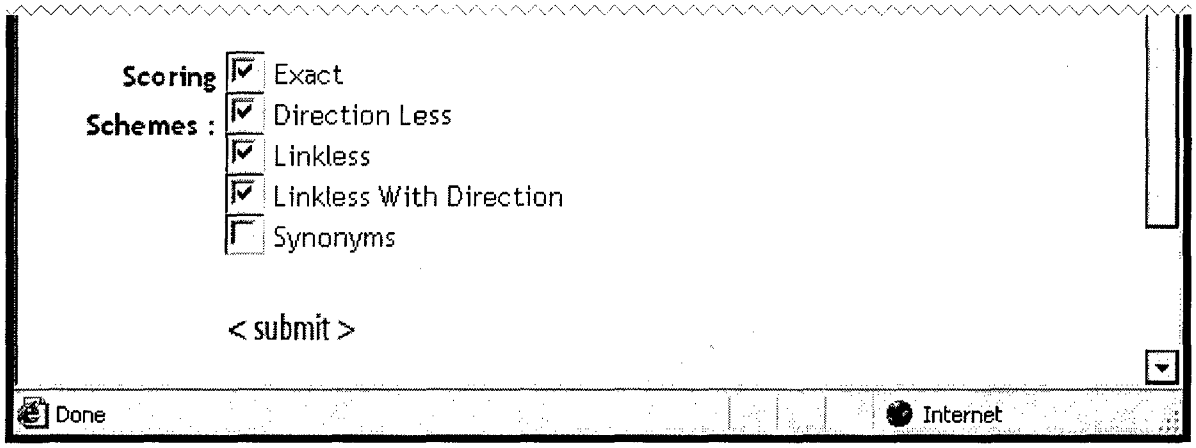


Figure 12. Semantic scoring dimensions.

Exact scoring produces the number of propositions in the student map that exactly match propositions in that expert's map.

Directionless scoring generates the number of propositions in the student map that match propositions in the expert map if you disregard the arrow direction but take into account the relationship label.

Linkless scoring produces the number of propositions in the student map that match propositions in the expert map if you disregard both the arrow direction and the relationship label.

Linkless with Direction scoring produces the number of propositions in the student map that match propositions in the expert map if you disregard the relationship label but take into account the arrow direction.

Synonym scoring produces the number of propositions in the student map that match propositions in the expert map when the links in both the student and expert maps are compared on a set of links (i.e., the synonym set). Synonym scoring is a more lenient method that yields a match if there exists an intersection between the set of synonyms in the student proposition and the set of synonyms in the expert's proposition.

For example, suppose the links *causes, leads to,* and *influences* were defined to be synonyms. A comparison between a student proposition and an expert proposition would yield a match if both the expert and student propositions had any of the synonyms (i.e., *causes, leads to,* or *influences*).

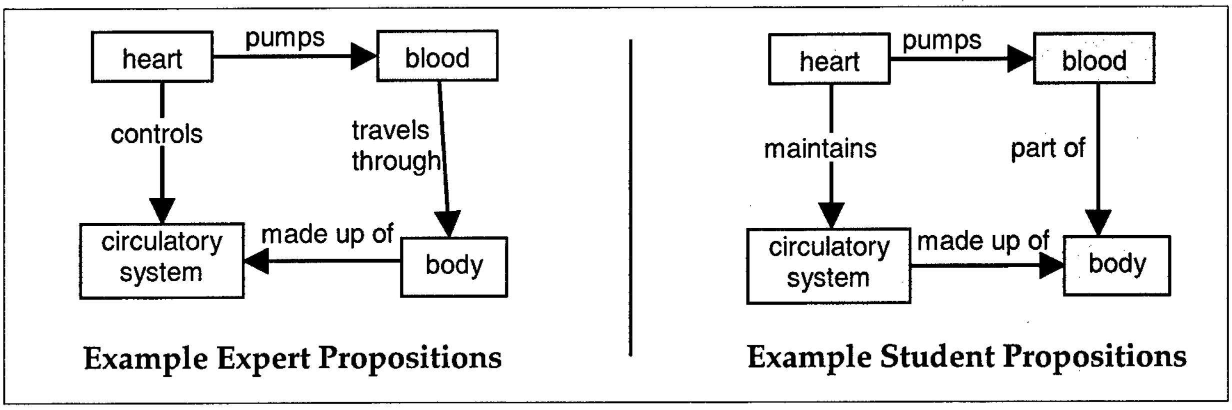


Figure 13. Example expert and student propositions.

To illustrate the different types of scores, Figure 13 shows examples of propositions from an expert and from a student.

Under Exact scoring, this student would only get 1 point, for the proposition **heart > pumps > blood**. The is the only proposition that has an exact match in the expert map, meaning both the arrow direction between the two nodes and the relationship label are the same.

Under Directionless scoring, the student would get 2 points. The proposition **heart > pumps > blood** gets 1 point, and another point is given for **circulatory system > made up of > body** because the nodes are connected by the same link the expert used, except the arrow direction is reversed in the expert map.

Under Linkless scoring, the student would get 4 points because arrow direction and link label are both disregarded. The student gets a point for relating two nodes in any way that the expert has connected. The propositions **heart > pumps > blood** and **circulatory system > made up of > body** both get a point each. In addition, the propositions **blood > part of > body** and **heart > maintains > circulatory system** also get a point each—this scoring scheme has found a match with the expert propositions that linked **blood** with **body** and **heart** with **circulatory system.**

Under Linkless with Direction scoring, the student would get 3 points. The proposition **heart > pumps > blood** gets 1 point, and points are given for **blood > part of > body** and **heart > maintains > circulatory system** because the relationship labels are disregarded, but the arrow direction of the relationships is taken into account.

Under Synonym scoring, suppose the links *controls* and *maintains* were defined as synonyms. There would be a match between the student and expert on the proposition **heart > maintains > circulatory system.**

Structural Scoring

Structural scoring is the second type of scoring scheme supported by the Authoring System. We are currently developing measures that report on the configural properties of the maps. For example, for each concept, the number of fan-in and fan-out connections are computed as well as the corresponding list of parent and descendant concepts, respectively. For each concept, reachability is determined (i.e., the set of concepts that could be reached from the current concept).

The fan-in value helps identify concepts that are sinks and the fan-out value helps identify concepts that are sources. Reachability is a measure of the network connectivity—the higher the number of concepts that are reachable from a node, the more interconnected the network.

To obtain structural map data, users select the option for structural scoring from the Reports page, and then choose the knowledge mapping task for which they want scores. They are then directed to a page that lists all the maps produced for that task. Users can either select multiple maps and download one Excel file with structural data for all the selected maps, or click on the S. Report link next to the map name to download structural map data for only that map (see Figure 14).

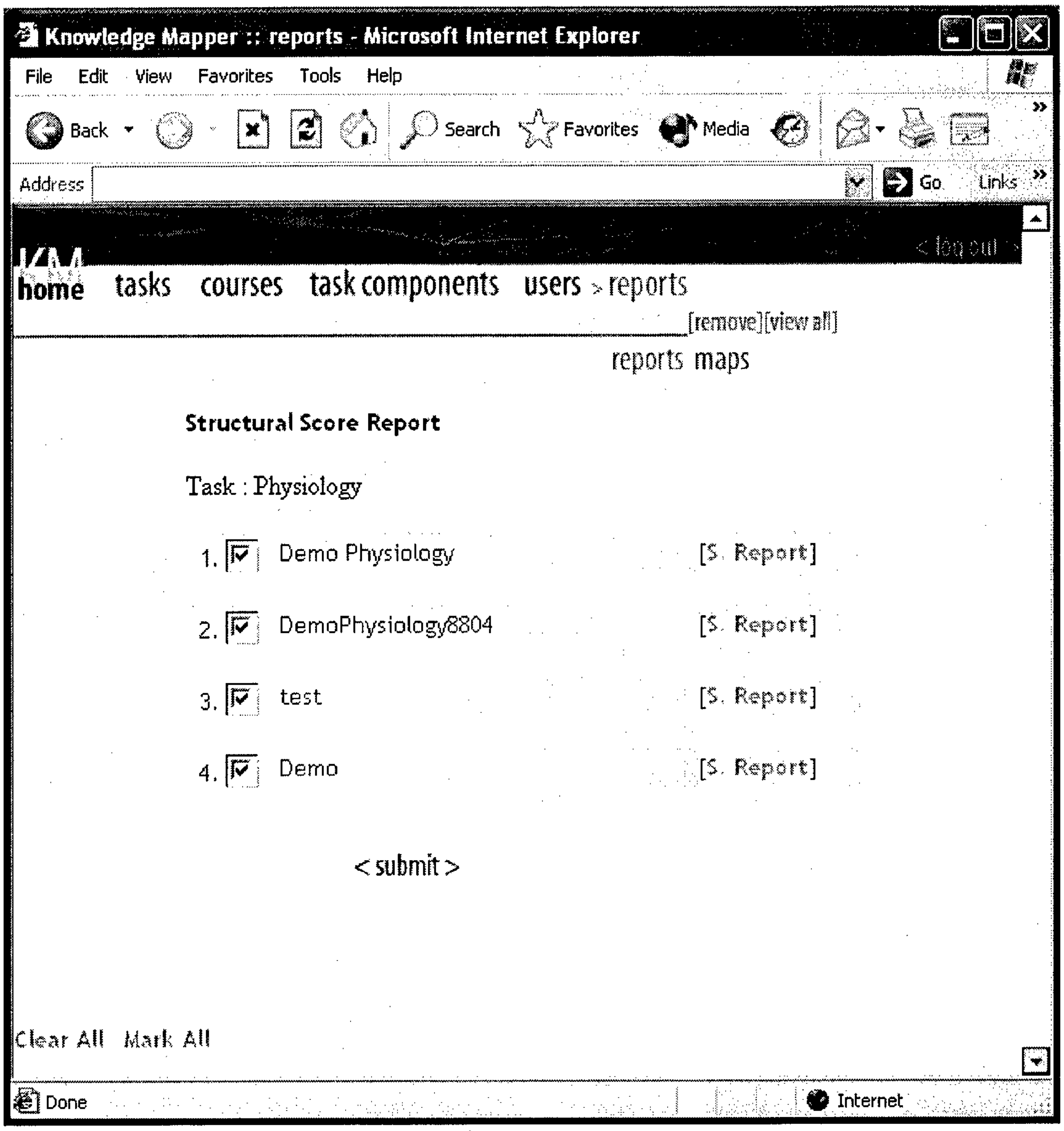


Figure 14. Structural Score Report page.

Task-Specific Scoring Schemes

The third scoring scheme currently available through the Authoring System is specific to the Target Error task. This scheme produces scores based on the physical placement of nodes on the canvas and employs algorithms tailored to the task to produce scores (see Chung, Michiuye et al., 2002, for an in-depth description of this scoring method).

Discussion and Next Steps

Our design goal for the authoring system was to develop a simple, user-friendly interface that would provide essential functionality with a minimal number of clicks. The authoring system is intended to allow a diverse set of users to create, modify, adapt, and reuse knowledge mapping tasks. Various scoring options provide information on student performance on different dimensions and different levels of stringency. The system stores student data and thus performance can be monitored over time.

We are currently conducting a usability study of the authoring system with a range of user types who we expect to be using this system (i.e., naïve user, task-familiar but unfamiliar with authoring). A continuing activity is to refine and extend the scoring to incorporate new developments as they mature. For example, a highly desirable feature is to incorporate scoring of student-typed links. We have made some progress toward this capability but lack sufficient data to fully test the algorithm. We also plan to expand the reporting capability to provide simple but useful reports for potential end-users (e.g., summary reports for groups of students, by task, by individual).

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